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Growing Princesa apples under semiarid conditions in northeastern Brazil

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ABSTRACT. Phenological observations are some of the most sensitive data for the identification of plant species growth in regional climate conditions. Thus, an experiment was conducted from October 2008 to December 2009 to characterize the phenological stages, fruit set and fruit yield of Princesa apples grown under a semiarid climate in northeastern Brazil. Phenological data (stages) were determined in the orchard by daily observations from bud breaking until fruit ripening. The following variables were evaluated: i) fruit set, which is the relation between the number of flowers and the number of fruits (%); ii) the number of fruit per plant; iii) the fruit production per plant (kg); and iv) the fruit yield (t ha^{-1}). Under semiarid conditions, the phenological cycle of Princesa apples is completed in 123 days and that it is possible to obtain apple yield under semiarid conditions with the pollinator cultivar. Furthermore, additional studies and more evaluation years are necessary to generate an apple production system that is reliable under semiarid conditions.

Keywords: *Malus domestica*, climatic conditions, phenology, cold hours requirement.

Cultivo da macieira "Princesa" sob condições semiáridas no Nordeste do Brasil

RESUMO. Observações fenológicas são os mais sensíveis dados para determinação de como as espécies de plantas respondem às condições climáticas regionais visando a produção de frutas em diferentes locais. Assim, o presente experimento foi conduzido de outubro de 2008 a dezembro de 2009 com o objetivo de caracterizar os estádios fenológicos, frutificação efetiva e produção de macieira Princesa, cultivada em clima semiárido do Nordeste do Brasil. Os dados fenológicos (fases) foram determinados no pomar de observações diárias desde a quebra de dormência até o amadurecimento de frutas, tendo as variáveis analisadas i) a frutificação: relação entre número de flores e número de frutos (%); ii) o número de frutos por planta; iii) produção de frutos por planta (Kg); e iv) produção de frutos (t ha^{-1}). Sob condições semi-áridas, o ciclo fenológico da macieira Princesa é concluído em 123 dias e é possível obter produção de maçãs sob condições semi-áridas. Além dissom, mais estudos e em mais anos de avaliação são necessários para obtenção de um sistema de produção de maçã sob condições semi-áridas.

Palavras-chave: *Malus domestica*, condições climáticas, fenologia, requerimento de frio.

Introduction

Apples are a fruit of worldwide horticultural importance, and Brazil is the eleventh top apple producer in the world (FAO, 2010).

Apple fruit trees grow well in temperate climate zones where most commercial varieties satisfy their required chilling temperature, which is often expressed as hours at less than 7°C (TROMP, 2005). In Brazil, the main apple varieties cultivated are Gala and Fuji, and the favorable climatic conditions for cultivation of these varieties are observed only in southern Brazil. More than 90% of the Brazilian apple fruit production comes from these two varieties planted only in the colder regions with altitudes above 900 m in southern Brazil (NACHTIGALL, 2004).

The main obstacle in the production of temperate fruit crops in tropical areas is the lack of effective accumulated chilling because warm winters result in prolonged dormancy leading to poor blooming, strong apical dominance, unsynchronized growth patterns and, consequently, low yields (COOK; JACOBS, 2000). One of the possible alternatives to avoid such problems is using low chilling requirement varieties, such as Anna (NJUGUNA et al., 2004) and Princesa apples, which have a low requirement for chilling from 350 to 450 chill units for satisfactory budding and blooming (NACHTIGALL, 2004). Another alternative is bringing the trees into an artificial dormancy by stopping the irrigation (JONES, 1987) and defoliating them by hand followed or not followed by chemical treatment to break dormancy (using oils or other chemicals).

Due to the worldwide economic importance of apples, some studies have been developed aiming to grow apples under different conditions from those required by this crop. Ashebir et al. (2010) studied apple growth under tropical mountain climate conditions in northern Ethiopia, and they concluded that it is possible to develop new apple production in the northern region of Tigray in Ethiopia where there is an average of 148 hours at less than 7°C per year during the dormant season. Moreover, the beginning of the apple tree blossom stage depends on annual deviations in air temperature, i.e., years with temperatures above normal in late winter and early spring are clearly related to negative anomalies in the date of the beginning of the blossom stage as observed by Chmielewski et al. (2004).

This study may lead to new solutions for crop diversification in irrigated areas of northeastern Brazil to meet fruit producer demands and to ensure the sustainability of fruit production. In addition, the strategy used in this study will enable the market to offer various products in different seasons.

The study of the phenological behavior of crops as a part of a well-characterized environment is important both to obtain satisfactory production results and to determine the most suitable agronomic techniques (VALENTINI et al., 2001), specifically for apples. Moreover, the study of phonological behavior is a useful system to study blooming in woody angiosperms (FOSTER et al., 2003).

The present work aimed at characterizing the phenological stages, fruit set and yield of Princesa apples grown under semiarid climate conditions in northeastern Brazil.

Material and methods

Plant material and growth conditions

Princesa apple (*Malus domestica*) trees propagated by grafting (with 'M9 filter and Marubakaido rootstock) and transplanted in 2007 were used in this study.

The study was conducted from October 2008 to December 2009 on the experimental orchard located in Bebedouro Experimental Station, which belongs to the Brazilian Agricultural Research Corporation (Embrapa Tropical SemiArid) in Petrolina (9°09' S and 40°22' W; at an altitude of 365.5 m above sea level), Pernambuco State, Brazil.

The climate of this region is classified as Bswh (Köeppen), which corresponds to a semiarid region with an average annual temperature of 26°C and average minimum and maximum temperatures of 21.2 and 32.7°C, respectively. The average annual rainfall is 481.7 mm, and the majority of the rainfall is observed during the months of February to April. The dry season occurs from June to November, and the average relative humidity is 67%. During the execution of the experiment, the climatic data were collected by a meteorological station installed inside the experimental station.

Apple trees were defoliated with 1.0% copper sulfate. After defoliation (August 5, 2008 and July 11, 2009), the apple trees were treated with 0.08% hydrogen cyanamide and 3.0% mineral oil (Assist®) following the recommendation of Petri and Palladini (1999). A completely randomized block design was used with treatments constituted by years (2008 and 2009), and the evaluations were subdivided into parcels of time. Four branches from 25 trees were selected at random and examined in 2008 (from October 5 to December 29) and 2009 (from July 11 to November 25) for daily monitoring.

The orchard conduction system was set up with a central leader, and it was composed of Eva, Condessa, Daiane, Gala and Princesa apple cultivars. The Princesa apple cultivar was the pollinator cultivar. In the orchard, one Princesa apple tree was planted for every five trees of the varieties cited. The spacing between the rows was 4.0 m, and the spacing between the trees was 1.3 m. The trees were drip-irrigated each day with ten self-regulated emitters per tree with a flow of 2 L $hour^{-1}$ based on daily evapotranspiration registers recorded by the local Bebedouro Meteorological Station and corrected according to the apple culture coefficient (Kc).

The soil from the study area was classified as a Red-Yellow Oxisol. The fertilization of the orchard was performed according to the recommendations of Nachtigall et al. (2004).

Variables recorded

Phenological data (stages) were determined in the orchard by daily observations from bud break (stage B) (Figure 1) until fruit ripening following

Fleckinger stages (GAUTIER, 1988). The duration of each phenological stage was recorded in number of days.

The following fruit variables were also recorded: i) fruit set, which is the relation between the number of flowers and number of fruits (%); ii) number of fruits per plant; iii) fruit production per plant, which was measured using a Filizola® CF15 brand precision scale (0.5 g precision) and expressed in kilograms (kg); and iv) yield, which was obtained by multiplying the fruit production per plant by the total number of plants in one hectare.

Experimental design and statistical analysis

Statistical analyses included descriptive and correlation analysis between the duration of each plant stage (in days) and each climatic variable in 2008 and 2009, and a t-test was used to compare years. All the calculations were performed using Assistat software.

Results and discussion

The phenological stages of the Princesa apple tree from bud break (stage B) until fruit ripening (GAUTIER, 1988) are shown in Figure 1.

The apple tree vegetative stage lasted from June to July (D_2 stage) with a difference of five days between 2008 and 2009 (Table 1).

In the 2008 and 2009 cycles, the F_2 phase reached 47 and 38 days, respectively, which was longer than that reported by Valentini et al. (2001), who characterized the phenological behavior of 15 different apple varieties and recorded an average duration of 35 days between the dormant bud and full bloom phases. Additionally, Valentini et al. (2001) reported ranges from 30 (Bouras cultivar) to 41 days (Rave V.G. variety) showing that some apple cultivars are compatible to the Princesa apple cultivar grown under a semiarid climate.

Table 1. Days needed to change the phenophases of Princesa apple at 2008 and 2009 cycles in Petrolina, Pernambuco State, Brazil.

Phenophases	Days		Bud (%)	
	2008	2009	2008	2009
A	1	1	100.0	100.0
B	15	8	76.1	60.9
C	29	23	3.5	18.3
C_3	30	24	2.1	12.2
D	33	27	3.5	7.8
D_2	34	29	4.2	8.7
E	37	31	2.8	15.6
E_2	40	33	4.2	13.0
F	41	36	4.9	15.6
F_2	47	38	4.2	13.0
G	48	39	5.6	18.3
H	49	41	24.6	24.4
I	51	44	7.7	23.5
J	54	46	4.9	33.0
L	146	126	2.33	10.2

A: dormant buds; B: beginning of swelling; C: green tips; C_3: half-inch green; D: half-inch green leafless; D_2: half-inch green leaves, E: green button, E_2: pink button, F: flowering start; F_2: full bloom; G: end of flowering; H: petal fall, I: fruit set; J: green fruit and L: fruit ripe.

The duration of each phenological stage differed between years studied (Table 1) showing that all stages in 2008 were longer than in 2009. The beginning of flowering (F stage; first flower) occurred five days earlier in 2009 than in 2008 (Table 1). The shorter phenological cycle from 2008 to 2009 (20 days in total) was caused by climatic factors, such as lower average temperature, lower global radiation, higher levels of relative humidity and higher levels of rainfall (Figure 2).

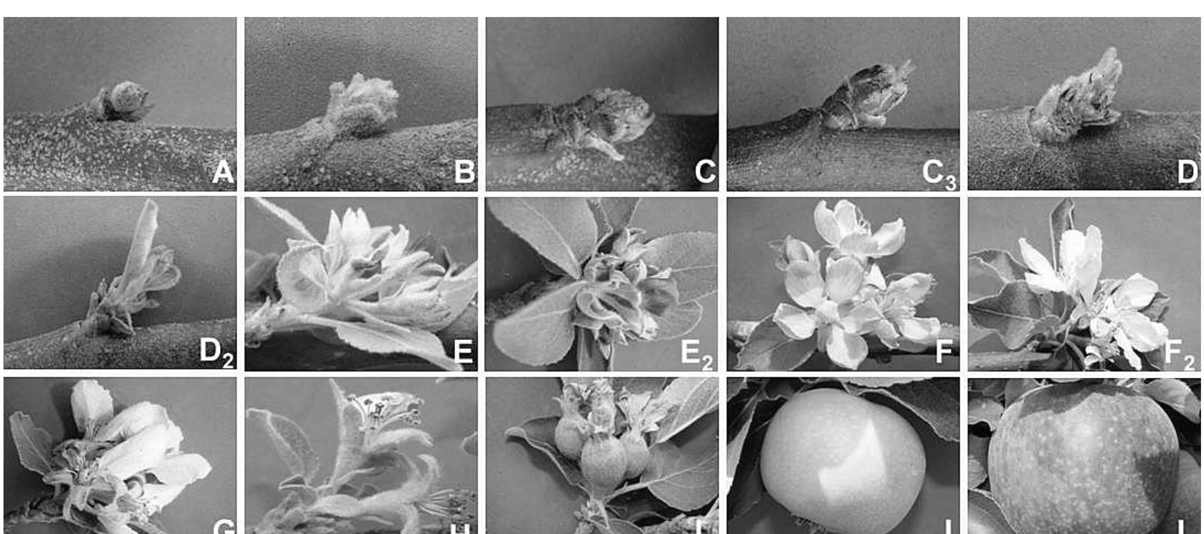

Figure 1. Phenological stages of Princesa apple tree, Petrolina, Pernambuco State, Brazil, 2009. A: dormant buds; B: beginning of swelling; C: green tips; C_3: half-inch green; D: half-inch green leafless; D_2: half-inch green leaves, E: green button, E_2: pink button, F: flowering start; F_2: full bloom; G: end of flowering; H: petal fall, I: fruit set; J: green fruit and L: fruit ripe.

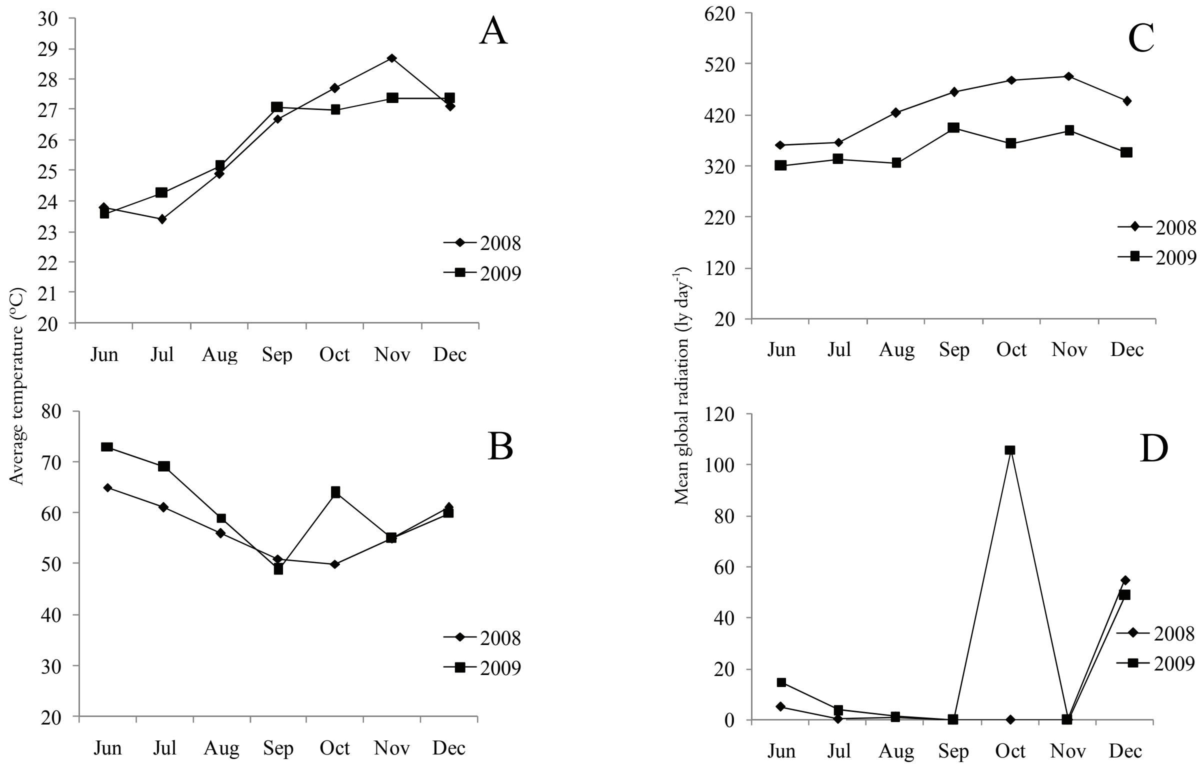

Figure 2. Average temperature (A), mean global radiation (B), relative humidity (C) and rainfall (D), from June to December 2008 and 2009 in Petrolina, Pernambuco State, Brazil.

Independently of the year (Tables 2 and 3), the apple phenophases were directly and positively ($p < 0.01$) correlated with air temperature with a range between 0.52 (2009) and 0.90 (2008). These results demonstrated that higher air temperatures generated longer phenological stages. Apple trees are commonly cultivated around the world in temperate zones where the relationship between air temperature and phenological stage duration is inverse. In a field study on apples in Germany, Chmielewski et al. (2004) observed that all phenophases are well-correlated to the average air temperature, thus indicating that higher temperatures after the winter accelerate developmental processes and ultimately lead to an advanced timing of spring events.

The results of the present study agreed with the findings of Sparks et al. (2000) and Chmielewski and Rötzer (2001), who explained that there are positive correlations between phenological phases and temperature, thus confirming the relationship between changes in air temperature and changes in the timing of the phenological stages.

With regard to the difference of apple tree phenological behavior in temperate and semiarid climates, it is important to remember that apple is a temperate crop and that it grows well in temperate climate zones where most commercial varieties satisfy their required chilling temperature, which is often expressed as the number of hours at less than 7°C (TROMP, 2005).

Chilling units accumulated during the cold season enable the plant to overcome dormancy (LEGAVE et al., 2008). Moreover, Iuchi (2006) explain that plant growth, phenology and fruit production are influenced by climatic conditions, such as air temperature, which may explain the disagreement of results from temperate and semiarid climates. According to Chmielewski et al. (2004), plant development and phenology strongly depend on air temperature after the release of dormancy. In the present study, it was not possible to accumulate cold hours, which highlighted the importance of irrigation efficiency. Chmielewski et al. (2004) explained that if temperature is increased, the biochemical reactions are accelerated up to a threshold where enzyme systems are destroyed and cells die. In the present work, this acceleration did not happen because the air temperatures during the time studied did not reach the threshold value for the Princesa apple cultivar. Furthermore, phenology is a sensitive biosphere indicator of climate change (WALTHER et al., 2002).

In addition to air temperature, relative humidity and rainfall were also positively correlated with the duration of apple phenophases in 2008 (Table 2), with an extremely high correlation coefficient (r = 0.86) for rainfall. According to this result, the rainfall in October of 2008 had more influence on the apple phenophases than relative humidity.

Table 2. Simple correlation coefficients (*r*) between climatic factors and phenophases of Princesa apples in 2008. Petrolina, Pernambuco State, Brazil.

	Phenophases[1]	Air Temperature[2]	RH[3]	Radiation[4]	Rainfall[5]
Phenophases[1]	-	0.5997*	0.5289*	-0.3868[ns]	0.8596**
Temperature[2]	-	-	0.4083[ns]	-0.3697[ns]	0.2424[ns]
UH[3]	-	-	-	-0.1134[ns]	0.3016[ns]
Radiation[4]	-	-	-	-	-0.3530[ns]
Rainfall[5]	-	-	-	-	-

1: Duration of phenological stages; 2: Average air temperature; 3: Relative Humidity; 4: Average Global Radiation; **: significant at 1% probability; *: significant at 5% probability; ns: not significant.

Table 3. Simple correlation coefficients (*r*) between climatic factors and phenophases of Princesa apples in 2009. Petrolina, Pernambuco State, Brazil.

	Phenophases[1]	Air Temperature[2]	RH[3]	Radiation[4]	Rainfall[5]
Phenophases[1]	-	0.5188*	-0.2465[ns]	0.3254[ns]	0.4130[ns]
Temperature[2]	-	-	-0.5501*	0.2635[ns]	0.1778[ns]
UH[3]	-	-	-	- 0.4543[ns]	-0.0191[ns]
Radiation[4]	-	-	-	-	0.0353[ns]
Rainfall[5]	-	-	-	-	-

1: Duration of phenological phases; 2: Average air temperature; 3: Relative Humidity; 4: Average Global Radiation; *: significant at 5% probability; ns: not significant.

Table 4 shows that all evaluated fruit characteristics were drastically and statistically higher in 2009 than in 2008, which may have been caused by the climatic conditions during this period. The fruit set average of Princesa apples in 2009 was higher than in 2008. This average (Table 4) was considered high because apples have a high rate of abscission; thus, they retain only 4-10% of their potential fruits according to Iuchi (2006).

The number of fruits per plant increased by 64.96% from 2008 to 2009 (Table 4). Independently of the year studied, all plants produced a lower number of fruits as compared to the number of fruits reported by others. Biffi and Rafaeli Neto (2008) studied Fuji apples in Brazil and reported a range of 394.43 - 293.09 for the number of fruits, and Fallahi (2007) studied Ryan Spur Delicious apples in the USA and reported a range of 624-630 for the number of fruits. In addition to the climate differences, this inferiority may be explained by the age of the plants in the present study because they were young and not at their full capacity for fruit production.

Fruit production per plant presented the same tendency of other fruit variables, i.e., results from 2009 were extremely higher than those from 2008 (Table 4). Fruit production per plant of the present study was lower than the results of Biffi and Rafaeli Neto (2008) in Brazil and Liu et al. (2008) in China. However, the fruit production results of the present study were higher than the 8.57 kg per plant reported by Santos et al. (2007) for the Clone 217 genotype in Portugal.

Yield is one of the most important characteristics of apple crops. From 2008 to 2009, the yield was increased by 9.16 t ha^{-1} (Table 4). The average values shown in Table 4 were lower than those presented by Gul (2005) in Turkey (24.25 t ha^{-1}) and by Nava and Dechen (2009) for Fuji apples in Brazil (16.1 t ha^{-1}). Moreover, the average yield values of the present study were compatible to the values reported by Naor et al. (2008) for 15-year-old Smoothie (a Golden delicious strain) apples grown in Israel (13.1 t ha^{-1}) and superior to the range reported by Di Vaio et al. (2009) for Annurca Rossa del Sud apples in Italy (7.4 - 25.1 t ha^{-1}).

Importantly, apple trees take four to five years to produce their first fruit (FERREE; WARRINGTON, 2003). In the present study, the trees were transplanted in 2007, so the fruit production was anticipated in three or four years. Moreover, it is common that the first harvest presents a low yield. Therefore, the continuous evaluation of the next harvests has crucial importance to determine and consolidate the viability of apple crops under semiarid conditions in northeastern Brazil because the preliminary results are satisfactory.

Table 4. Fruit set, number of fruits per plant (NFP), fruit production per plant (P/P) and yield of Princesa apples. Petrolina, Pernambuco State, Brazil.

	Fruit Set (%)		NFP		P/P (kg)		Yield (t ha^{-1})	
	2008	2009	2008	2009	2008	2009	2008	2009
Magnitude	2.86	9.00	47.00	139.00	5.12	17.35	10.46	33.37
VC (%)	6.28	20.83	16.17	45.35	14.64	45.92	14.64	45.92
Variance	1.94	4.34	234.92	302.71	2.41	9.24	10.73	34.19
Average	2.33 b	10.20 a	20.48 b	58.45 a	1.54 b	6.62 a	3.57 b	12.73 a
SD (%)	1.08	2.08	9.50	26.50	0.35	3.04	1.28	5.84

VC=variation coefficient; SD=standard deviation.

Accordingly, most apple cultivars require cross-pollination using a compatible cultivar to obtain desirable set fruit, and the Princesa apple cultivar is used for cross-pollination and not for yield. In comparison to apple cultivars traditionally grown for yield in productive regions, Princesa apple results were previously expected to be lower, but according to the present work, this apple cultivar (Princesa) has potential for apple production under semiarid climate conditions. However, further studies are necessary.

Conclusion

Thus, the results of this study indicated that the phenological cycle of Princesa apples is completed in 123 days and that it is possible to obtain apple yield under semiarid conditions with the pollinator cultivar. Furthermore, additional studies and more evaluation years are necessary to generate an apple production system that is reliable under semiarid conditions.

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